AN INTRODUCTION TO
PRACTICAL
ORGANIC CHEMISTRY

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No. IV.

AN INTRODUCTION TO PRACTICAL ORGANIC CHEMISTRY.

WITH REFERENCES TO THE WORKS OF DAVY, BRANDE, LIEBIG, ETC.

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WILLIAM PICKERING.
1843.

IN former times when science, like coaches, travelled at a leisurely pace, it was not difficult to keep up with it, or at least, to be left at no very great distance behind: its practical results were taught by fathers to their sons, and a new edition of an encyclopædia published once in about fifty years, sufficed for all common demands. But this century has altered the face of things: the science learned in our childhood avails not for our manhood; fresh discoveries and fresh practical applications of them occur every day, and every year wants its new encyclopædia. The consequence of this is, that seeing science flying onward at railroad speed, men despair of even keeping it in sight, and renounce the chase as hopeless; and thus there is danger that the mass of mankind may become more ignorant, in proportion as the few grow wiser.

But however impossible it may be for those involved in the daily business of their respective callings, to follow up the smaller details of natural science, there are always a few great principles from which all the rest must spring; and the very nature of truth is, that it is simple and easy of comprehension. To acquire these, therefore, requires no long time or great stretch of application; yet these being once fixed in the mind, the foundation is laid, and we can build as much upon it afterwards as we please.

It is the object of the present little work to give a few of the great principles which a very interesting portion of modern science is grounded upon; and by omitting technical details, to make it available to the unscientific reader. There is much in Prof. Liebig's views of organic chemistry which may enable the gardener and the farmer to work on a more rational plan; much which may tend to the preservation of health by showing the relation of diet and air to the well-being of the body, and, in consequence, to that of the mind; for, as was well observed by an excellent man now deceased, "If the body have not a due share of attention, it will make the soul pay dear for its lodging."—In this little treatise, therefore, as much as may serve these purposes is brought forward in as simple a form as the nature of the subject will allow. The compiler has sought no scientific fame; his only wish has been to afford some useful knowledge to such of his countrymen as have not the means of seeking it in a more elaborate form; and if he should thus be able in some cases to give his readers a more enlarged view of what, as a whole, is called nature, i. e. the aggregate of the forces and their results, by virtue of which the visible world has become what it is:—if by a clearer view of these he should enable him also to arrive at a clearer view of the Supreme Mind which impressed its own stamp on the whole:—if in addition to this he should have given the busy man assistance in his honest calling, or aided him in preserving health to pursue it, he has gained his object, and seeks no other reward than the consciousness of having endeavoured to be useful in his generation. Many years probably will not elapse ere he will have to give an account of the talent entrusted to him; but he knows that the Master he has served is wont to look rather at the motive of his servants, than at the imperfect execution of their purpose:—to that generous Master he dedicates his small work.

INTRODUCTION.

1.

THE material substances which compose the earth, its atmosphere, and its inhabitants, are continually changing their forms and combinations, though remaining the same in quantity; for, as far as we can tell, no atom of the material universe is ever lost, through all its multiplied transformations. The science which takes cognizance of the laws by which such changes are wrought is called Chemistry.

2. The substances thus wrought upon are either *inorganized*,—as stones, earths, &c.; which are without any internal mechanism for effecting such changes; or *organized*,—as plants, animals, &c. which are possessed of a systematic mechanism for attracting and assimilating other substances, and effecting constant change in their own constituent parts.

3. All substances, whether organized or inorganized are resolvable into certain elements;—that is, substances which as far as we know at

present, contain only one kind of matter. These are supposed to be about fifty-five,* of which four chiefly contribute to the formation of organized matter, though about eight more enter into it in small proportions.

4. All material substances are conjectured to be composed of indefinitely small atoms which are capable of being more or less separated under different circumstances; and thus all are considered as susceptible of three forms—i. e. solid, in which they are so closely pressed together as to resist our touch:—liquid, in which being less compact, they yield to it:—aeriform, in which they are so widely separated as nearly to elude it. Thus, most metals, at a sufficiently high temperature, first become fluid, and at an increased degree of heat pass off in vapour.

5. All elementary substances combine in definite proportions; as 1 to 1,—1 to 2,—1 to 3,

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* These consist of the metals, in number about forty-three, and twelve other substances more difficult to characterize. i.e. 1. Oxygen. 2. Chlorine. 3. Iodine. 4. Bromine. 5. Fluorine. 6. Hydrogen. 7. Nitrogen? 8. Sulphur. 9. Selenium. 10. Phosphorus. 11. Carbon. 12. Boron. *Brande's Man. of Chem.* p. 350, 5th ed. Silicon, or the basis of flints, is by some reckoned as a metal, by others as one of the substances allied to Boron, &c.

&c.* If, on mixing two substances, there be more than enough for one proportion and not enough for the next, the surplus remains uncombined.

6. All elementary substances have a certain disposition to unite with other substances, which is called *chemical affinity:* and when to two substances already in combination, a third is pre-

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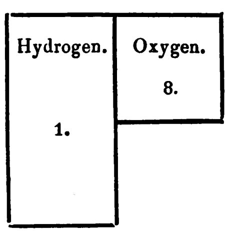
* In the course of this work the definite quantity of any substance capable of uniting with another substance, will be termed a proportional or equivalent part, whatever its bulk or weight may be. The proportion of hydrogen which unites with oxygen to form water is generally assumed as the unit, hydrogen being the lightest known substance; and the following diagram may then be considered as representing the relative bulk and weight of one proportional part of hydrogen and one of oxygen,



i. e. the same bulk of oxygen would weigh 16 times as much as hydrogen does. Thus half the bulk and eight times the weight, forms the definite proportion in which oxygen unites with hydrogen in the formation of water.

sented for which either of the first has a greater attraction, it quits its former companion and passes into combination with the new one, leaving the first free.* The combinations thus formed, whilst their union remains unbroken, may be considered as compound atoms, which are capable of entering into other combinations. As, for instance, an acid which is a compound of two elements, has a strong affinity for an alkaline base, which is also a compound of two elements. Their combination forms a third substance, unlike either; yet from it the original compounds may be recovered. In some cases these original compounds are decomposed with great difficulty.

7. Chemical combinations as well as their decomposition are mainly effected through the influence of an agent whose mode of action is as yet in some degree unknown. We call it *electricity*. If a glass tube, or a piece of sealing wax be rubbed, the first with a warm dry silk handkerchief, or the second with a warm dry flannel, they will be found, whilst thus excited, to possess the power of attracting light bodies, such as feathers, &c.; but as soon as the feather

* This action was formerly called, after Bergman, *elective* affinity.

has been in contact with the glass or the sealing wax, if again brought near, it will be steadily repelled; for the excited body has communicated its excitement to the feather, and it is a law of electricity that *bodies similarly excited repel each other*. The electricity of glass when rubbed is *positive*,* and the feather by contact has become *positively* electrified. It will now be attracted by the sealing wax in which the rubbing has excited negative electricity: for *bodies differently electrified attract each other;* and in like manner a feather which, by contact with the sealing wax, has acquired negative electricity, will now fly from the body which first excited it, and be attracted by the different electricity of the glass. If, after having tried this experiment, the feather be brought near either the silk or flannel rubber, it will be found to approach the silk, if it flies from the glass; and the flannel, if it flies from the sealing wax, and vice versa; thus showing that *in case of friction, the rubber and the substance rubbed will be differently electrified*. If the above

* This was at first called *vitreous*, and the *negative* state excited in sealing wax by friction *resinous* electricity.

experiment be made in the dark, a pale light or sparks will be seen to issue from the excited substances with a slight crackling noise. Upon a larger scale the same agency produces lightning, which is but a large electric spark passing from one excited body to another dissimilarly excited. The mode in which clouds, electrically excited, attract or repel each other in spite of wind, is to be explained by the first mentioned laws of electricity.

8. If two metals, platinum and zinc, for instance,—be placed together alternately, so that at one side the platinum, at the other the zinc be outermost; and a wire be attached to each of the outside plates,—as soon as the whole is brought into activity by some fluid which acts chemically on either of the metals, and at the same time connects them, the wire attached to the corroded metal, which in this case will be the zinc, will be found positively, whilst that attached to the uncorroded, which will here be the platinum, will be found negatively electrified. Whilst the wires remain in contact a silent electric action is kept up in the circuit thus formed, which somewhat raises the temperature of the battery, as this system of plates is called, but is not otherwise perceptible; but if the circuit be

broken by removing the wires to a small distance from each other, then the action already going on in the wire communicates itself to the intervening particles of air, and light and heat are evolved so intense, if the battery be a powerful one, as to equal the sun in brilliance, and fuse the most refractory metals.*

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* As the researches of Professor Faraday have thrown much new light on the subject of electricity, it may be useful here to explain the terms which he has adopted in his writings on the subject. Considering electricity as a force acting along a series of contiguous particles in one or another direction, he terms the respective ends of the wires *electr-odes* from ὁδος *a road or way*. Then hypothetically assuming electricity to be a movement due to the contrary movement of the earth, he considers this movement to be communicated in the same course with that apparently followed by the sun; and from *ανω up*, i. e. the sun's rising, and *κατω down*, i. e. the sun's setting, he forms *an-ode* and *cath* or rather *kath-ode*, to express the respective parts of the *dielectric*; i. e. the substance acted upon by electricity: the anode being the part at which electricity may be said to enter the dielectric, the kathode that at which it leaves it. The anode therefore is that part of the dielectric which is nearest the zinc or positive wire, and therefore according to the law of electricity it will itself be negative; while the kathode, being nearest the platinum or negative wire, will be positive, and transmit the action. Bodies capable of decomposition by electric action, he terms *electrolytes*, from *λυω dissolve*; and the component parts of

9. If, when a galvanic battery † is thus excited, the two electrode wires be plunged into water, bubbles will be seen to arise: if then glass vessels capable of receiving the gas thus disengaged be placed over the wires, it will be found that oxygen gas has passed off from the positive, and hydrogen from the negative wire: the water gradually diminishes, and the whole is at last decomposed into its elements; the oxygen occupying exactly half the space occupied by the hydrogen and weighing eight times as much. In this manner *all substances composed of only*

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these bodies he terms *ions*, from *ιον a thing that goes*, and as there are certain classes of substances which show themselves at the anode, and others at the kathode, he terms these an-ions or kat-ions according to their natural tendency. Thus water, being decomposed by electric action, the oxygen will show itself at the zinc wire: the water surrounding that wire is the anode of the dielectric, therefore oxygen is an an-ion, and in its nature negative: the hydrogen is evolved at the platinum or negative wire: the water around that is the kathode; and hydrogen is accordingly by nature a kat-ion. Oxygen, chlorine, acids, &c. are anions; combustible bodies, most metals, alkalies, and bases are generally kat-ions.

† This arrangement of electric force is sometimes called a galvanic battery, sometimes a voltaic pile; from the names of the discoverers of this form of electricity,—Galvani and Volta.

two elemental parts, seem capable of separation by electric action * as long as they are in a fluid state. Chloride of silver for instance when fused will evolve chlorine at the positive wire and

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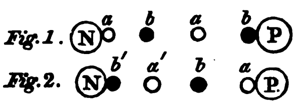
* In explanation of this fact Professor Faraday proposes a theory so consonant with all the phenomena, and so simple at the same time, that it is impossible not to receive it as the truth: for it has the stamp of every true law of nature, power and simplicity. "Electro-chemical decomposition" he says, "appears to me to be produced by *an internal corpuscular action*," as thus:



"The effect," he says, "is considered as essentially dependent upon the mutual chemical affinity of the particles of opposite kinds. Particles *a a* fig. 1. could not be transferred or travel from one pole N towards the other P unless they found particles of the opposite kind *b b* ready to pass in the contrary direction: for it is by virtue of their increased affinity for those particles, combined with their diminished affinity for such as are behind them in their course, that they are urged forward: and when any one particle *a* fig. 2. arrives at the pole, it is excluded or set free, because the particle *b* of the opposite kind, with which it was the moment before in combination, has, under the superinducing influence of the current, a greater attraction for the particle *a′* which is before it in its course, than for the particle *a* towards which its affinity has been weakened."—In proof of this brilliant metallic silver at the negative.† Compounds of a more complex nature sometimes resist voltaic action and sometimes are decomposed by a secondary action arising from the affinity of some of the parts for the fluid or the metals of the battery.

10. The source of voltaic electricity is the chemical action of the oxygen of the connecting fluid on the metal which by its position is positive. Thus much is proved: but *how* the chemical, or electrical force which appears to be almost identical with it, acts on or by the particles of matter, remains still a subject for farther investigation; for though natural organs, as in the gymnotus and the torpedo, magnetic force, electricity produced by friction on a glass cylinder, and lightning, are all identical with voltaic electricity in their effects, their causes remain as yet more obscure. The magnetic power communicated to a piece of common soft iron by a

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may be given the fact that many substances which either do not conduct electricity at all, or very feebly, in a solid state, conduct freely, and generally with a decomposition of the constituent parts, when made liquid. *Faraday's Experimental Researches in Electricity*, 4th and 5th series. See also *Davy's Elements of Chem. Phil.* p. 487.

† Faraday's Researches, 8th series.

helix, i. e. a spiral coil of copper wire wound round it, as long as this wire forms part of a voltaic circuit,—seems to indicate some natural polarity in the particles of matter which shows itself as soon as some moving cause has placed them in the requisite position; for the magnetism ceases as soon as the circuit is broken by disconnecting either end of the wire from the battery:—but as this is no place for hypothesis, the reader must seek for information on this head elsewhere.

11. The elementary substances which form the chief ultimate constituents of organic matter, are, Carbon, Hydrogen, Nitrogen,* or as it is sometimes called, Azote, and Oxygen: besides these, small portions of Sulphur, Phosphorus, Chlorine, Iodine, and a few of the metals enter occasionally into organic compounds. Of these, Oxygen, Chlorine, Iodine, Sulphur, Phosphorus, Nitrogen, and Carbon belong to the class of

* The experiments of Mr. Knox,† if confirmed by further examination, will remove nitrogen from the class of elementary substances. Sir H. Davy suspected that it had a metallic base from the property which ammonia (a compound of nitrogen and hydrogen) possesses of

† Transactions of the Royal Irish Academy, for 1841.

An-ions†—the metals belong chiefly to that of Kat-ions, as does Hydrogen, if we may judge from the place it takes when water is decomposed.

12. Oxygen is the most generally diffused of all these elements, and performs the most important part in nature: for besides constituting a large part of the atmosphere which surrounds the earth, it enters into the composition of almost all the minerals found on its surface:—in silica, which is a component part of a vast many of them, it forms half the weight of that earth. In an isolated state it is a gaseous body without taste or smell; in combination, if in large quantity, it produces an acid; thus sulphuric and nitric acids are formed by the union of a large proportion of oxygen with sulphur or with nitrogen. In a less proportion it forms non-acid compounds, termed oxides. One of these we are familiar with in the shape of rust or

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forming an amalgam with mercury when submitted to voltaic action in contact with that metal, and from finding occasionally on decomposition more hydrogen than enters into the composition of ammonia. Mr. Knox has decomposed nitrogen into silicon and hydrogen. Silicon probably, though never yet reduced, is a metallic oxide.

† Thomson on Heat and Electricity, p. 438, 2nd Edit.

oxide of iron, which is formed by the action of the oxygen of the air or the water on the metal. The earths are chiefly oxides of metals. It combines rapidly with carbon, giving out heat.

13. Hydrogen has a strong affinity for oxygen, with which it unites to form water. The whole process of decay depends on this affinity, as well as many of the processes for the nutrition of plants. Hydrogen, when in the state of gas, is very combustible, and is the lightest body known, but it is never found in an isolated condition.

14. Nitrogen is very indifferent to other substances, and apparently reluctant to enter into combination with them. When forced by circumstances to do so, it seems only to remain combined by a sort of indolence of nature,* and is easily separated again. Thus in plants and other organized bodies, the moment that it is released from the control of the vital power, it

* If, as before noticed, nitrogen be a compound, this peculiarity is explained; for all bodies formed of compound atoms are more easily decomposed than those which are more simple in their formation. In this case silicon being an *an-ion*, and hydrogen a *kat-ion*, its indifference to other substances is not wonderful.

assists decay by escaping from the compounds of which it formed a constituent part.

15. Carbon has a very considerable range of affinity. It unites with oxygen in two definite proportions, and thus forms two different gaseous compounds, i. e. carbonic acid, and carbonic oxide. The first of these is emitted in immense quantities from many volcanoes and mineral springs, and is produced by the combustion and decay of organized matter. In absolute purity carbon constitutes the diamond: it is more commonly seen mixed with other substances in the form of charcoal, as well as in the mineral called plumbago or black lead, of which, in the purest specimens, it forms nine tenths.

16. Chlorine at all common temperatures and pressures is a gaseous fluid. It is reckoned as yet among simple substances, and is found in combination with soda in common salt. It combines with oxygen and forms acids.* Iodine is a soft friable substance, which evaporates easily. It is obtained from sea weed and sponge, and in small quantities from sea water. Like chlorine it unites both with oxygen and hydrogen, and forms acids. Phosphorus is found chiefly in

* It unites with hydrogen to form muriatic acid.

organized bodies: it inflames readily, unites with oxygen and forms acids; and is found in nature combined with lime or with magnesia. For chemical purposes it is obtained from calcined bones. Sulphur is well known. The metals or rather their oxides, combine with acids and form salts.

17. "The substances which constitute the principal mass of every vegetable are compounds of carbon, with oxygen and hydrogen in the proper relative proportions for forming water. Woody fibre, starch, sugar, and gum, for example, are such compounds of carbon with the elements of water."* In other substances the oxygen is in excess, and to this class belong the chief of the organic acids found in plants. In others the hydrogen is in excess; such are the volatile and fixed oils, and the resins.

18. The juices of all vegetables contain organic acids, generally combined with inorganic bases† or metallic oxides. All acids, whether organic or inorganic, have a tendency to unite with alkaline bases, and thus form neutral saline

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* Liebig Agric. Chem. p. 6.

† Thus called because when combined with acids they form the base of a new substance.

compounds. These combinations, whatever be the base, are always effected in definite proportions: that is, one equivalent of an acid always unites with one or more equivalents of a base. Thus one proportion of potash unites with one proportion of sulphuric acid, and forms sulphate of potash; or with two proportions of the same acid, and forms bisulphate of potash: the potash itself being a metallic oxide:—(of potassium.)

19. "Nitrogen is an element of vegetable albumen and gluten: it is a constituent both of the acid and what are termed the indifferent substances of plants, as well as of those peculiar vegetable compounds which possess the properties of metallic oxides and are known as organic bases." Estimated by its proportional weight nitrogen forms only a very small part of plants; but it is never entirely absent from any part of them. In animal bodies it is found in much larger proportion.

20. The ordinary constituents of atmospheric air may be considered to be:—

	by measure.	by weight.
Nitrogen	77.5	75.55
Oxygen	21	23.32
Aqueous vapour	1.42	1.03
Carbonic acid	0.08	0.10

Extraneous matters, however, occasionally find their way into the atmosphere: in London traces of sulphurous and sulphuric acid are observable, and also of sulphate of ammonia;* and, during a storm, nitric acid may be formed from the combination of the oxygen and nitrogen of the air effected by electric action. Near the sea traces of salt may be found in it, which sometimes is deposited on the leaves of vegetables. Generally speaking, however, the above proportions remain unaltered, except in confined situations, notwithstanding that the innumerable animals which respire atmospheric air return a volume of carbonic acid equal to that of the oxygen in the air absorbed; the nitrogen being expired at the same time unaltered:—notwithstanding, too, that carbonic acid is one of the ultimate products of animal and vegetable decay; and that immense quantities of this gas are emitted from the depths of the earth in volcanic districts.—Whence comes the oxygen which maintains a constant proportion in the air? and how is this abundance of carbonic acid disposed of?—In order to answer these questions the already noticed constituent parts of plants should

* Brande's Man. of Chem. 5th Ed. p. 452.

be taken into consideration. They are found by experiment to evolve a much larger quantity of oxygen during the day, than at any time enters into their constituent parts; it is therefore clear that this substance must be derived from some other source. The elements of vegetable matter are mainly carbon with hydrogen and oxygen in the proportions which form water: and the nourishment of plants must be drawn from the atmosphere through the leaves, or from the soil through the roots. The quantity of vegetable matter produced on 26,910 square feet of forest, meadow, or arable land, yields from 1109 to 1124 lbs. of carbon:* a quantity so large that were it taken annually from the soil, and, as is usually the case, only a small part of it returned in manure, the proportion of this element would be sensibly decreased in the course of culture: but chemical analysis has proved the reverse of this to be the fact. It remains clear then that the larger part of the carbon found in plants does not come from the

* Liebig Ag. Chem. p. 19. Sir Humphry Davy entertained the same opinion as to the function of plants in balancing the state of the atmosphere. V. El. of Chem. Phil. p. 234.

soil,—and if the researches of Liebig are not altogether fallacious, we must look for the source of it in the atmosphere, where it exists in the shape of carbonic acid. Now carbonic acid contains one proportional part of carbon and two of oxygen: hence, in the process of assimilating the carbon for the growth of the plant, two proportionals of oxygen are constantly liberated. Furthermore, the elements of water are, one proportional of hydrogen and one of oxygen, and as hydrogen no where exists in a separate state, those plants which possess an excess of this element must have derived it from the decomposition of water, and they will thus have liberated a farther portion of oxygen. Growing plants, therefore, are the constant purifiers of the air, which they render fit for respiration by absorbing the carbonic acid gas which it is charged with, and restoring its oxygen disengaged from carbon, which latter substance is retained and assimilated for the nourishment and growth of the plant.

21. One interesting observation here presents itself and deserves to be noted. It is a matter of certainty that when Moses was recording the order of creation, the only writer, be it observed, whose cosmogony presents this order:—he must

have been entirely ignorant of the sciences which now enable us to trace it with some degree of confidence. Let us consider the apparent course of creation as these sciences,—chemistry and geology—present it. From the seething matter of volcanoes, carbonic acid, combinations of ammonia in a gaseous form, chiefly carbonate of ammonia, and aqueous vapour are evolved,* i. e. gases composed respectively of carbon and oxygen, and hydrogen and nitrogen, or a combination of both,† but none of them capable of maintaining animal life; and steam, which is a compound of oxygen and hydrogen. Plants sprout from the earth, and find nourishment for the most luxuriant growth in the gaseous products of the heated mass. The remains of enormous ferns found among deep beds of coal, showing the latter to be the produce of a former vegetation, prove how immense a portion of

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* Neither oxygen, hydrogen, nor nitrogen are found in a separate state in nature.

† Carbonic acid is 2 proportions of oxygen.

	1	carbon.
Ammonia is	3	hydrogen.
	1	nitrogen.

Carbonate of ammonia consists of one proportion of carbonic acid and one of ammonia.

vegetable matter was produced from gases which no animal could have breathed. The absorption of carbonic acid with the consequent return of a large quantity of pure oxygen to the atmosphere; the greater affinity of hydrogen for the oxygen thus presented than for nitrogen, especially when heat acted in the decomposition of ammonia which would then set free its portion of nitrogen—brought the atmosphere apparently in the course of time to its present composition, and animals then stepped forth upon the earth, to breathe the air, and consume the food already prepared for them. Such is the account which science would give; it differs in nothing from that of Moses.

22. But though the use and interest of chemistry be great, even whilst taking cognizance only of inorganized nature; it assumes higher ground when it enters upon the inquiry into the laws which regulate organized bodies. We there behold operations going on which no human art can imitate, though they are evidently in accordance with the known properties of inorganized matter. We see one force after another added which does not arise out of any action of the former ones, yet harmonizes with them, till, if candid, we are compelled to acknowledge that

these superadded forces which we can neither create nor control;—which chemical affinity, so far from controlling, at times yields to, though still unsuperseded,—must spring from another and a higher source;—from an Intelligence, in short, which having given laws to matter in the first instance, knew how to make those laws available to nobler purposes than the mere crystallization of a rock, or even the coherence of a planet. It is in these higher operations that we shall now trace the course of chemical action.

PART I.

Plants and their Nourishment.

23.

IN the ovum of the animal and the seed of the plant there is a germ of organism, which, under certain circumstances, is brought into activity; and by absorbing and assimilating substances proper for its nourishment, fresh parts are added, and growth ensues. The greater portion of the ovum, or seed, consists of substances, which, when the necessary conditions of warmth, moisture, &c. exist,* are absorbed and decomposed in the minute vessels of the germ. From the fluids thus generated fresh

* During the germination of plants electricity is evolved—the carbonic acid disengaged is found to be charged with positive electricity, exactly as in the case of combustion. The seeds themselves in consequence become negative. V. *Thomson on Heat and Elect.* pp. 445-576. They germinate better when connected with the negative extremity of a voltaic battery than with the positive; for the alkalies requisite to their growth accumulate around the negative electrode.

matter is deposited, which being permeated by the fluid amid which it is formed, necessarily assumes a cellular or tubular form. The organism having now assimilated the whole substance of the seed, the radicle bursts the skin already softened by moisture, and seeks fresh nourishment in the earth, while the seed leaves push upwards to seek the like from the air. The farther growth of the plant must of course depend on the quantity of substances suited to its increase which lie within its reach; and the whole art of culture consists in affording the young plant this food: for as no elementary substance can be *generated*, but is only *assimilated* by organism, it is necessary that these elements should be presented to it in sufficient quantity. The exact nature of the power which regulates these processes, and which we term the vital force, is unknown to us as yet. We know that it controls the chemical affinities of inorganic substances so far as to hold some in combination which would not otherwise unite; and to decompose others which, under any other circumstances, are very difficultly decompounded. Like other forces it seems to have a certain limit, and no sooner is its control removed or overpowered than the ordinary laws of chemical affinity resume their sway, and an entire dissolution of the organism takes place.

24. It has already been observed that the elements of increase are derived from the soil and the atmosphere; for uulike the animal, which requires that its food shall be matter already organized, the vegetable draws its nourishment altogether from inorganized matter. We have seen that abundance of the nourishment requisite for the first vegetation might be obtained from the air, and it is remarkable that the remnants of this vegetation found in coal beds, shew it to have consisted of such plants as have the largest extent of leaf, and the least of root; thus presenting an extended surface for the absorption and assimilation of the elements contained in the atmosphere. With the first developed leaf this process commences: during the day carbonic acid is absorbed and decomposed, pure oxygen being given out; but during the night this process of decomposition, which has been excited by light and heat,* ceases;

* Even among inorganized substances light is generally necessary to facilitate the process of decomposition. This is greatly accelerated by the direct hot rays of the sun: in some cases the rapidity with which the change takes place under these circumstances is such as

and the carbonic acid which is absorbed, either by roots or leaves, is given out again undecompounded. The oxygen of the air now resumes its powerful chemical action upon the plant; mixes with its component parts, and forms acids.* A curious proof of this is afforded by the leaves of the *Cotyledon calycinium*, the *Cacalia ficoides* and others; for they are sour like sorrel in the morning, tasteless at noon, and bitter at night. The formation of acids is effected during the night by a true process of oxidation: these are deprived of their acid properties during the day and evening, and by the separation of a part of their oxygen are changed into compounds containing oxygen and hydrogen, in the same proportions as water, which is the composition of all tasteless substances, or as the day advances

to occasion explosion, as in the case of chlorine and hydrogen.

* Sir H. Davy found that acid and alkali might be obtained from a growing plant by making it a medium of communication between the two extremes of a Voltaic battery: wires from these extremities were plunged into two cups of distilled water, and the cups were united by means of a sprig of mint dipping into both. In ten minutes potash and lime appeared in the negative cup, while an acid was found in the positive cup.—*V. Thomson on Heat and Electricity*, p. 574.

The action of weak currents of Electricity in many of and more oxygen is separated, with an excess of hydrogen, which is the composition of all bitter substances.* Hence we may account for the greater quantity of acid in fruits ripened during cold cloudy summers, when, from the lack of the sun's direct rays, the process of decomposition is comparatively slow; or in those ripened artificially in winter, when there are fewer hours of daylight. Hence too, as the nights grow longer, the alteration of colour, and final dropping off of leaves:—the quantity of oxygen absorbed during the absence of the sun, effects changes greater than the short, and often cloudy days of winter can remedy; less carbon is assimilated,—the leaf loses its green colour,—decay commences,—and it falls off.†

25. Besides woody fibre, which consists of

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the great operations of nature is only just beginning to be studied: much that is now obscure in the growth and assimilation of vegetable bodies will probably be found to have its origin in the different electric states produced by the sun's rays, or the variations of the atmosphere.

* Liebig Agric. Chem. p. 32.

† Evergreen leaves absorb less oxygen from the atmosphere than others. The leaves of the *Ilex aquifolium* absorb only 0.86 of their volume of oxygen gas in the same time that the leaves of the poplar absorb 8, and those of the beech 9½ times their volume.

carbon, with hydrogen and oxygen in the proportion which forms water; starch, sugar, and gum, which are formed of the same elements, though with a less proportion of carbon;—caoutchouc, wax, fat, and volatile oils, which consist chiefly of carbon and hydrogen;—plants contain other substances into which nitrogen enters as an element, and which are indispensable to the nourishment of the animals feeding upon them. "These important products of vegetation are especially abundant in the seeds of the different kinds of grain, of pease, beans, and lentils; and in the roots and juices of esculent vegetables. They exist however in all plants without exception. These nitrogenized forms of nutriment in the vegetable kingdom may be reduced to three or four substances, easily distinguished by their external characters. When the newly expressed juices of vegetables are allowed to stand, a separation takes place in a few minutes. A gelatinous precipitate is deposited, which, when washed from the colouring matter, becomes a grayish white substance, which has been termed *vegetable fibrine.* The juice of grapes is especially rich in this constituent; but it is most abundant in the seeds of wheat, and of the cerealia generally. It may be obtained from wheat flour, it is then called *gluten*, but the glutinous property belongs to another substance, present in small quantity, which is not found in other cerealia. The second nitrogenized compound remains dissolved in the juice after the separation of the fibrine; but the moment it is heated to the boiling point, it separates as a coagulum, which cannot be distinguished from that formed by the serum of blood, or the white of an egg when boiled in water. This is *vegetable albumen*. The third nitrogenized constituent of the vegetable food of animals, is *vegetable caseine*. It is chiefly found in the seeds of beans, peas, &c.; —is soluble in water, does not coagulate when heated, but is coagulated by an acid exactly in the same manner as animal milk.* The nitrogen which enters into these compounds is derived from the decomposition of ammonia, for the nitrogen of the atmosphere enters into no combinations, and passes off unaltered even when respired by animals. This ammonia is thrown out largely from volcanoes in the shape of carbonate,—that is, combined with carbonic acid—and results also from the decay and consequent decomposition of

* Liebig. Animal Chemistry, p. 45.

animal and vegetable matter. Though not readily detected in the atmosphere, its constant presence in rain water shows that it must exist there; but plants probably take it up largely through their roots also.

26. Though carbonic acid, water, and ammonia, are necessary for the existence of plants, because they contain the elements from which their organs are formed, other substances are likewise requisite for the formation of certain organs destined for especial functions peculiar to each family of plants.* These are the salts formed by the combination of organic acids with metallic oxides or bases. *Phosphate of magnesia* in combination with *ammonia* is an invariable constituent of the seeds of all kinds of grasses; it is found in the outer husk; and in the outer part of the leaves and stalk is found a large quantity of silicic acid and potash, in the form of acid silicate of potash.† Sulphate of lime‡ is found in clover, and nitrate of soda in barley: common salt is a very frequent ingredient in marine plants; phosphate of lime is found in oats, and some other seeds, and nearly

* Liebig. Agric. Chem. p. 90.

† Liebig.

‡ Gypsum.

all vegetables yield traces of oxide of iron, and many of oxide of manganese.* The sap of trees has generally been found to contain salts of lime and potassa.

27. But besides these salts of mineral acids, which are absorbed from the earth in a state of solution, most plants, perhaps all of them, contain organic acids, all of which are in combination with bases such as potash, soda, lime, or magnesia.†—Now as we know that acids and bases always combine in definite proportions, it follows that if the soil does not produce the base in sufficient quantity to saturate the acid, the plant cannot be in a healthy state. Hence it becomes necessary to choose particular soils for certain plants, or to supply the deficiency in the soil by manure. To supply the silicate of potash, which is so needful to the stalks of the grasses, and especially of wheat, a sufficiency of potash and of silica must exist in the earth; and the want of the former substance in sandy and calcareous soils, renders them unfruitful in corn and grasses, while turnips and other plants which need little of it thrive exceedingly well.

* Brande.

† Viz, the oxides of the metals, potassium, sodium, calcium, and magnesium.

Argillaceous (clayey) soils generally abound in potash, and accordingly are fruitful in grass and corn. But even those will be exhausted of their potash by a recurrence of corn crops, unless it be in some manner restored by carrying back the straw in the shape of manure. Of these crops wheat is the most exhausting; for though the ashes of wheat, barley, and oat straw, consist of the same substances, an hundred parts of wheat straw yield 15·5 parts of such ashes, while that of barley yields 8·54, and of oats only 4·42.* On the other hand beans contain scarcely any alkalies, buck wheat 0·09 per cent. only; and they are equally poor in the phosphates of lime and magnesia. Lucern belongs to this latter class of plants. Beet, which contains little else than sugar, water, and a small quantity of cellular tissue, is one of those crops which consume scarcely any of the substances required by wheat.†

* Liebig. Agric. Chem. p. 143. The learned professor records that a melted vitreous mass was found in a meadow between Heidelberg and Manheim after a thunder storm. This mass was found on examination to consist of silicate of potash. A flash of lightning had struck a stack of hay, and nothing was found in its place but the melted ashes of the hay.

† "Beet root in 100 parts contains about 89 parts

28. It has been proved by experiment that the substances received into the sap, and distributed into the different parts of plants for their renewal or increase, must be in a state of solution—i. e. either liquid or aeriform. This is owing to the minuteness of the vessels whose mouths, thickly set over the roots and leaves, act as a sponge, and absorb whatever fluid comes within their reach, but which, like a sponge, are unable to receive any solid even in the state of the finest dust. These fluids are received indiscriminately; are there decomposed, and, as it were, selected by the organs through which they are transmitted, and all useless portions of them rejected again by the roots, or exhaled through the leaves. This excrementitious matter in time accumulates round the roots, to the exclusion of proper nourishment: hence the benefit of digging hops, &c. which removes the excrementitious matter and supplies fresh soil; yet notwithstanding this, after a time it is found that the soil becomes so impregnated with them as to be unfit for the

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water, and 11 parts solid matter, which consists of from 8 to 9 per cent. sugar, and from 2 to 2½ per cent. cellular tissue. Sugar contains 42.4 per cent.,—cellular tissue 47 per cent. of carbon."—Liebig. Agric. Chem. p. 18.

growth of this species of crop, though exceedingly fertile for a different one. Fruit trees which have ceased to bear well, may be again made fruitful by removing the earth round the roots, and replacing it with fresh soil; and practically it is known that where a tree has died, it is needful to subject the spot to a course of digging and tillage ere another is planted, or the young plant will not thrive.

29. In some cases the substances thrown off by the roots are not rejected merely in the same state as received; they have entered into fresh combinations, and thus present themselves in the form of extractive matter, sometimes resinous and acrid, in which case probably an excess of hydrogen has contributed to their formation; sometimes mild, resembling gum, which latter, though its ultimate elements are those of woody fibre, i. e. carbon and water, yet contains a less quantity of carbon. Trees whose wood is very solid, and which consequently appropriates much carbon, frequently throw out gum from the bark: it is probably in that case a residuary compound. These excrementitious substances, though useless and even poisonous to the plant which has thrown them off, may in some cases afford nourishment to plants of a different kind; and this

is the cause why the alternation of crops has been found practically useful. This again has been found by experiment. The water in which plants of the family of the *Leguminosæ** grew acquired a brown colour. Plants of the same species placed in water impregnated with these excrements were impeded in their growth, and faded prematurely; whilst, on the contrary, corn plants grew vigorously in it, and the colour of the water diminished sensibly; so that it appeared as if a certain quantity of the excrements of the *Leguminosæ* had really been absorbed by the corn plants."† But even if not absorbed, these vegetable excrements, which necessarily contain a considerable portion of carbon, will in the course of tillage be exposed to the action of the atmosphere, the oxygen of which will soon convert carbon into carbonic acid, and hydrogen into water; and thus, in the course of a few years, they may again be a source of fertility. Unslacked lime by hastening the decomposition of vegetable matter, assists this process; itself absorbing a portion of the carbonic acid thus generated, and again becoming a carbonate.‡

* *Podded*, such as peas, beans, &c.

† Liebig. Agric. Chem., p. 153.

‡ The limestone or chalk from which lime is obtained

30. The decay of vegetable matter generally yields a substance which has been termed ***humus:*** it consists mainly of carbon, and when exposed to the action of the atmosphere its surface becomes oxidized, and carbonic acid is generated. In careful tillage, whatever portions of this substance may be contained in the soil, are in turn exposed to the air, and give off a portion of their carbon in this manner; thus contributing to the nourishment of the plants growing within its reach—for carbonic acid gas being soluble in water it is absorbed by the roots along with the moisture of the earth. As the oxygen can act only on the surface however, its decay is slow; thus it remains as a store from which a certain portion of the nutriment of plants may be obtained by diligent culture: otherwise, unless the soil should be one which the air easily permeates, it remains inert.—It can only be made available by the presence of oxygen. As charcoal has the same property of forming carbonic

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is itself carbonate of lime, i. e. the oxide of lime, formed by the action of the oxygen of the atmosphere on the metal calcium, combined with carbonic acid. The carbonic acid is expelled by heat, and oxide of calcium is again produced, but this has a great affinity for water and for carbonic acid so that it quickly passes into fresh combinations.

acid, it has been found serviceable, when powdered, in promoting the growth of plants.

31. We have seen that the excrementitious matter thrown off by the roots of plants is of two kinds—in the one case it consists merely of inorganic substances which cannot enter into the organism of the plant, and may be considered as undigested matter: this, though useless to one kind of plant may be needed by another. In the other case it has entered into combination and produced matter which may be decomposed, and again made available to the same kind of plant in the shape of humus. How soon this decomposition shall take place depends on the nature of the soil, but we may take it as a general rule that it will be hastened by alkalies, which, if there be any acids present, will unite with them and form soluble salts, leaving behind the other matters, which will consist chiefly of carbon. No manure will make a soil fit for the growth of the same species of plant till this decomposition has taken place, and sometimes this is not till after a lapse of some years.

32. The production of coal beds has been the result of this process of decay under peculiar circumstances. Woody fibre and parts of plants having been found in it in different stages of

decomposition, leave little doubt as to its origin; and as, wherever moisture is present, oxygen is so too, there would be a continued evolution of carbonic acid gas from vegetable matter in a state of decay till all the oxygen was consumed; but as two proportions of oxygen to only one of carbon are required to form this gas, a considerable portion of carbon must remain, as well as the hydrogen which had been in combination with the oxygen, while both those elements existed in the form of water. The results of a chemical analysis of canel coal from Lancashire justifies this assumption. 24 proportions of carbon and 13 of hydrogen are found in it, but no oxygen.* The accumulation of carbonic acid gas in mines, wells, caves, &c. is in many instances the result of this vegetable decomposition still going on.† It is well known that the gas produced by distillation of coal contains a considerable proportion of hydrogen, which having little affinity for carbon quits it easily. It was a component part of the water always found in woody and vegetable matter, and was left behind when the

* Liebig. Agric. Chem. p. 350.

† Professor Liebig conjectures that the crystallization of the diamond may be effected in the course of this kind of decomposition.

oxygen united with the carbon to form carbonic acid. The fire damp of mines, like the gas obtained by distillation, consists mainly of carburetted hydrogen. Bituminous substances have the same origin; they consist merely of carbon and hydrogen.*

33. The nourishment to be afforded to plants may now be easily summed up. They require a large supply of carbon in solution generally found in the shape of carbonic acid; of hydrogen and oxygen chiefly received in the form of water; of nitrogen derived from ammonia either existing in a gaseous form in the air, or dissolved in the rain water which impregnates the earth round them with its elements:—of potash, soda, lime, magnesia, silica, iron, and manganese, with phosphorus and sulphur in the form of acids forming neutral compounds, chiefly with the above named bases. The art of culture consists in restoring or affording these substances to the *soil*—for the air we are unable to impregnate by any agency of ours;—and in proportioning the allowed growth of the tree or vegetable to the quantity of nourishment at our command. A tree will not form blossoms and fruit unless

* Brande.

it has a surplus of nutriment—it will therefore form none if all the carbon it can derive from the carbonic acid around it, whether in the soil or air, be consumed in the formation of the woody fibre of very numerous branches:—the removal of a few of these in the spring causes an immediate surplus; and hence the pruning of fruit trees makes them bear more abundantly.

34. It has already been noticed that silicate of potash is a necessary ingredient in the stalks of grasses or corn;—that phosphate of magnesia or phosphate of lime is no less needful to the husks of the seed;—and that there are other substances, which form their chief nutritive qualities, into which nitrogen must enter largely.—A farmer who has attended to this will notice if his corn appear weak in the stalk, and will endeavour to supply the first of these substances: it will be found in the decomposition of straw; it may be even obtained in mass under the title of soluble glass. If the ears be small and insufficient, the phosphates may be supplied from bone dust, which consists mainly of the phosphates of lime and magnesia,* or from bran which

* "The manure of an acre of land with 40lbs of bone dust is sufficient to supply three crops of wheat, clover,

has been used in print works, which contains these phosphates, after it has served the purpose of the manufacturer; or from the excrements of animals which have been fed upon corn.* The nitrogenized products must be increased by a

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potatoes, turnips, &c. with phosphates. But the form in which they are to be restored to a soil does not appear to be a matter of indifference. For the more finely the bones are reduced to powder, and the more intimately they are mixed with the soil, the more easily they are assimilated. The easiest mode of effecting their division is, to pour over the bones in a state of fine powder, half their weight of sulphuric acid diluted with three or four parts of water, and after they have been digested some time, to add one hundred parts of water, and sprinkle this mixture over the field before the plough." Liebig. Agric. Chem. p. 173. It must be remembered that when sulphuric acid is to be diluted, *the acid must be slowly added to the whole quantity of water*, or a degree of heat will be generated which may be mischievous. The corrosive nature of sulphuric acid renders great caution needful in the use of it.

* Five hundred grains of horsedung on being subjected to chemical analysis were found to contain—

Water	357 . 0
Vegetable fibre and animal matter	135 . 0
Silica	3 . 2
Phosphate of lime	0 . 4
Carbonate of lime	1 . 5
Phosphate of magnesia and soda	2 . 9
	500 . 0

supply of ammonia, and this may be gained in different ways. All animal excrements contain it:* the decay of animal and vegetable matter affords it in notable quantity; and gypsum (sulphate of lime) is sometimes exceedingly useful in fixing these ammoniacal compounds thus formed, no less than that which is found in rain water. "The carbonate of ammonia contained in rain water is decomposed by gypsum, soluble sulphate of ammonia, and carbonate of lime, are formed; and this salt of ammonia possessing no volatility, at common temperatures, is consequently retained in the soil. All the gypsum gradually disappears, but its action upon the carbonate of ammonia continues as long as a trace of it exists."† If gypsum be strewed on

* It should, however, be noticed, that the extremely volatile nature of this substance leads to its almost immediate escape into the surrounding atmosphere; and thus, when manure of this kind is laid in a heap, and turned, as is the practice with farmers, this most valuable constituent part is almost entirely lost.

† Liebig. Agr. Chem. p. 85. It must, however, be remarked, that gypsum requires water to produce its effects.—Liebig recommends a salt more easily soluble in very dry land—chloride of calcium for instance. In England, however, the winter's rain will generally supply moisture enough.

the floors of stables it has the same effect: by decomposing the ammoniacal salts which are formed, and which form the disagreeable odour by their constant volatilization, it fixes them as sulphate of ammonia, and thus no part of the manure is lost; as this can afterwards be carried out upon the land. It has the further effect of destroying the unpleasant odour; for these odours, in this as in other cases, are the result mainly of volatile ammoniacal compounds. Where grasses are scanty in leaf, a larger supply of potash will generally increase the crop;—and this substance will be found abundantly in wood ashes—in the excrements of the cow and sheep, which contain but little nitrogen;—and of course it may be supplied from the potash of commerce. If it be suspected that there is a want of carbon, powdered charcoal may be strewed on the soil: this will be found useful in heavy soils; coal ashes, too, or burnt earth, or fine gravel, will act mechanically on such soils, by dividing and making them permeable to the atmosphere, and thus increase their fertility. Chalky soil might be improved by pouring dilute sulphuric acid upon it, which by converting the chalk (carbonate of lime) into gypsum (sulphate of lime) would create this useful substance upon the spot. It will follow from what has been said that the only use of fallowing ground, exclusive of the mechanical one of destroying troublesome weeds, consists in the opportunity it affords of turning up fresh surfaces to the action of the atmosphere, and recruiting its nitrogen by the rain water which falls on it. It may therefore be a matter of calculation to the farmer, whether he may not find the manure requisite to supply the place of this less costly than the loss of a crop.

35. Besides the nitrogenized products already mentioned, there are in plants other compounds destined to play an important part both in the support of graminivorous animals, and in the reproduction of the plant itself. "A new and peculiar process of vegetation ensues in all perennial plants after the complete maturity of their fruit. The stem of annual plants, at this period of their growth, becomes woody, and their leaves change in colour;—they have no further increase to provide for:—the leaves of trees and shrubs, on the contrary, remain in activity until the commencement of winter; but after August they form no more wood: all the carbonic acid which the plants now absorb, is employed in the production of nutritive matter

for the following year. Instead of woody fibre starch is formed, and is diffused through every part of the plant by the autumn sap. The barks of several aspens and pine trees contain so much of this substance, that it can be extracted from them, as from potatoes, by trituration in water. It exists also in the roots and other parts. A very early winter, or sudden change of temperature, prevents the formation of this provision for the following year; the wood is said then not to ripen, and its growth the next season is very limited.*

36. The starch accumulated in the autumn in the bark of the root, and the seed, under the requisite conditions of moisture and warmth, is converted into sugar and gum,† and from this the bud, the young plant, or the leaves of the bulb, derive the juices which enable them to form a fresh organism and derive fresh nutriment

* Liebig. Agr. Chem. p. 119.

† The elementary proportions of starch are, carbon 12, hydrogen 10, oxygen 10,—or, a certain quantity of carbon combined with the elements of water. It becomes gum by the addition of one proportion of water—(for the formula of gum is carbon 12, hydrogen 11, oxygen 11,) and sugar by a still farther addition of water—(sugar from starch contains carbon 12, hydrogen 14, oxygen 14.)

from the atmosphere. Every one knows practically, that when potatoes have germinated they become sweet, and their mealiness is lost: the starch is become sugar for the support of the young shoot. It is thus that barley is converted into malt; by supplying the conditions of moisture and warmth, the seed is made to germinate, and the starch contained in it is thus converted into sugar. The process of growth is arrested before this sugar is consumed for the nourishment of the young plant, by subjecting the grain to the heat of a kiln; and thus the sweetness is preserved.

37. The quantity of either starch or gluten contained in the plant, depends on the kind of nourishment it is supplied with: when manures, containing nitrogen, have been used, the nitrogenized products will be increased, and the starch lessened, and vice versâ. Thus potatoes grown in a soil which has been treated with animal manure, which contains much nitrogen, have a gluey consistence; while those grown in a fresh soil where humus abounds, have more of starch, and are what is called mealy. Wheat is influenced in the same manner, and gives a larger proportion of gluten or of starch, according to the manure that has been used on the soil.

38. We have now traced the great laws of vegetable life, but there are still some remarkable processes connected with vegetable death, which remain to be noticed. These are what are commonly termed fermentation, putrefaction, and decay.

39. We have already seen the facility with which starch changes into sugar, and sugar into other products, in the living organism, by the addition or subtraction of the elements of water; for it can hardly be doubted that the sweet juice of the young grain, is in itself the foundation of the flour in the ripe one: a portion of water has been abstracted from the sugar, and it is again become starch. When the juice of fruits, containing saccharine matter, or a solution of grain, in which the starch has again been converted into sugar, is exposed to the air, two fresh substances (carbonic acid and alcohol), are engendered, and the sugar disappears—the process by which this is effected, is commonly called fermentation. On examination, these two products will be found to contain the original elements of the sugar differently arranged, and with the addition of a certain proportion of the elements of water. The immediate cause of the change appears to be a nitrogenized substance in the

juices of the plant, which has been termed albumen or gluten. The peculiar indifference of nitrogen to other elements, has been noticed; no sooner is it free from the vital force, than it seeks its liberty; the elementary atoms are thus set in motion, and like grains of cork floating in water, group themselves afresh according to the most powerful affinity: the movement is propagated from one to another, and ceases not till all have ranged themselves in their new combinations. When the carbonic acid, which escapes in a gaseous form from fermenting sugar, and the alcohol which remains in the liquor are analyzed, it appears that the elements of the sugar are there, with a slight addition of oxygen and hydrogen,* the known elements of water, which has probably been absorbed from the air in the course of the chemical change going on. Other products also are found, the result of the decomposition of the nitrogenized matter.

* Cane sugar contains the elements of carbonic acid and alcohol, *minus* one proportional part of water. The alcohol and carbonic acid produced by its fermentation, contain together one equivalent of oxygen and one of hydrogen, (that is, one proportional of water), more than the sugar contained. *Liebig. Agr. Chem.* p. 183.

40. Whilst the decomposition of the vegetable albumen is still going on, it is termed yeast or ferment, and if a portion of it be taken from the fermenting liquor, and added to any other saccharine matter, it has the property of communicating its state of chemical change, i. e. movement—to that also. The process is repeated, and the results are the same; with this difference merely, that if the substance which the yeast has been introduced into, contains no albumen, it disappears after a time, all its parts having entered into fresh combinations: whereas if it meets with albumen, it communicates its state of decomposition to this also,—and a larger quantity of ferment is the result. It sometimes happens that if the quantity of albumen be sufficient to keep up this state of chemical movement, even the fresh combinations are disturbed; the oxygen of the air is attracted, and the alcohol having a larger quantity of oxygen added to its other elements, becomes acetic acid. By preventing the access of atmospheric air, this change may be prevented, for the great element of the change is then wanting.

41. Putrefaction is another result of the disposition of nitrogen to escape from, or change its companions. As soon as a body, in which

the vital force has ceased to act, and which contains nitrogen, is exposed to moisture, the nitrogen combines with the hydrogen of the water, and the carbon with the oxygen, and thus ammonia and carbonic acid are evolved—the atoms once set in motion run through a course of different combinations, and for the most part disappear in a gaseous form, leaving, at last, nothing but the bony structure behind. The disagreeable odours emitted by bodies in this state of change are these gaseous products,—compounds, in various forms, of hydrogen and nitrogen,—for oxygen and carbon are inodorous.

42. Decay is the gradual oxidation of organized bodies, where there is not moisture sufficient to admit of the rapid changes which take place in fermentation and putrefaction. The carbon of the decaying body unites with the oxygen of the atmosphere in the proportion of one to two, and is thus slowly abstracted: or, as in cases where it is in great measure secured from the access of air,—with its own oxygen; leaving an extra quantity of hydrogen, as has already been noticed in the instance of coal. Human bodies when kept perfectly dry, do not putrefy, but become shrunken and dark coloured.

43. We have now traced the general laws by

which organic compounds are formed, and again decomposed—most simple even in their complexity; accomplishing the most enormous results by means as small in appearance as they are mighty in operation. "Carbonic acid, water, and ammonia, contain the elements necessary for the support of animals and vegetables. The same substances are the ultimate products of the chemical processes of decay and putrefaction. All the innumerable products of vitality resume, after death, the original form from which they sprang. And thus death—the complete dissolution of an existing generation—becomes the source of life for a new one."*

* Liebig. Agr. Chem. p. 89.

PART II.

Animals and their Nourishment.

44.

WE have seen that among inorganic substances combinations are effected, and changes wrought by means of a peculiar property, which, till better understood, has been termed chemical affinity. In plants a new principle is superadded, and chemical affinity is modified by a mechanism which, under the external influence of light and heat, causes fresh combinations and products, and possesses the power of growth and reproduction. In the animal this mechanism no longer requires external influence, but contains within itself the mainspring which regulates its movements. This mainspring is the apparatus of the nerves.

45. Assimilation, or the process of formation and growth, goes on alike in the plant and the animal; in both it is carried on unconsciously, and thus far the difference between the two lies

only in the *source* of motion. The lower order of animals possess merely the organs of this vegetative life, but as we ascend higher, we find new organs introduced, nerves of sensation receive impressions from without, and propagate their movements through nerves of motion; higher yet we find sensation concentred in the brain, and voluntary movement transmitted from thence to the limbs.

46. In man, we find a more delicate mechanism acting as the organ of a farther force, which manifests itself in the higher mental phenomena, and which occasionally accelerates, retards, or disturbs the process of vegetative life. Of its nature science can say little; we only know that it exists, that in its action it is frequently independent of external sensations, and that in so far as its manifestations are connected with matter, its agency "is entirely distinct from the vital force, with which it has nothing in common. Thus two forces are found in activity together; but consciousness and intellect may be absent in animals as they are in living vegetables, without their vitality being otherwise affected than by the want of a peculiar source of increased energy or of disturbance. Except in

regard to this, all the vital chemical processes go on precisely in the same way in man, and in the lower animals." *

47. The first process of vitality is assimilation. The young animal, like the germ of the plant, has a peculiar nourishment and shelter provided for it during the first stages of its growth; and like that, its increase of mass proceeds from a fluid which conveys and deposits the matter requisite for the formation and increase of each organ; and as in plants too, these must be received in a state of solution. The young animal receives its food in a fluid state: it is the office of the stomach in after life, to reduce to that state such parts of the solid food received, as may be fitted for nutriment. In either case, the fluid is absorbed by minute vessels, which, like those in the root of a plant, act as a sponge, and suck in whatever liquid is presented to them, without discrimination. The fluid, which is the final result of the moisture thus obtained, we term *blood;* and by depositions from it, all increase of mass, or reproduction of parts is effected. The matter deposited amid a permeating and circulating liquid neces-

* Liebig. Anim. Chem. p. 6.

sarily assumes, as in plants, the form of tubes and cells.

48. At a certain period of its growth the young animal, like the young plant, requires fresh nourishment, and breaks forth from its first shelter to seek it. It is now subjected to the action of the atmosphere, respiration ensues, and thenceforth air is no less needful to life than food; nor can any other air than the precise mixture of gases found in the atmosphere, be respired long without danger. At every breath a certain quantity of this air is inhaled: the same volume of air is exhaled a moment after, but its qualities are changed; the nitrogen is indeed returned unaltered, but the oxygen has disappeared, and in its room we find carbonic acid and watery vapour. The weight of oxygen thus abstracted from the atmosphere daily, is considerable,* yet we find no increase of weight in the body receiving it, if it be that of a full grown animal. It is evident then that it does not remain in the system, and we find in fact that it escapes in combination with carbon and

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* An adult man inhales on an average 32½ oz. of oxygen; a horse 13 lbs. 3½ oz.; a milch cow 11 lbs. 10¾ oz. in twenty-four hours.

with hydrogen, which two elements, combined with oxygen, form respectively carbonic acid and water. The elements for this combination then must have existed in the body. It is well known that gases possess the power of penetrating membranes; and thus the oxygen of the atmosphere when received into the lungs, penetrates the coats of the vessels there exposed to it, and finds its way into the blood. Oxygen is too powerful an agent ever to remain inactive; a course of chemical combinations takes place, the blood is changed in colour and properties, and carbonic acid is evolved. A large proportion of chemical combinations are attended with the evolution of heat, as may be seen in the processes of fermentation and putrefaction, if the mass be sufficient to prevent the heat from escaping, and among these are the combinations taking place within the living body. Carbon forms a large constituent part of all food, as well as of all the tissues of the body; now a charcoal fire is nothing more than carbon in a state of rapid combination with the oxygen of the atmosphere,* during which also carbonic acid is largely

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* In what we call "making a fire," we only resort to the same principle which has been noticed § 40. To

evolved. The combination which takes place in the body is not so rapid, but it is of the same nature. "Respiration is essentially a combustion of carbon, which in combining with oxygen is converted into carbonic acid, and at the same time furnishes the animal heat. Liebig calculates that the amount of carbon daily burned in the body of an adult man, is about fourteen ounces, and that the heat given out by this quantity is fully sufficient to keep up the temperature of the body, and to account for the evaporation of all the gaseous matter and water expelled from the lungs."*

49. But the quantity of oxygen inspired is affected by the temperature and density of the atmosphere. At every respiration a volume of air enters, proportioned to the capacity of the chest, but its weight, and consequently that of the oxygen it contains, is not constant. Air is expanded by heat, and contracted by cold, there-

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facilitate combination, we bring a substance, already in a state of chemical decomposition, into contact with the substance we wish to decompose. Combustion, like fermentation, may be spontaneous; but it is hastened and rendered easier by thus artificially throwing the atoms into a state of movement.

* Turner's Chemistry, 6th Edit.

fore a given volume of cold dense air will contain more atoms of oxygen than an equal volume of warm rarefied air. The oxygen taken into the system is given out again in the same forms, whether in summer or in winter; hence we must expire more carbon in cold weather, because we have inspired more oxygen, and we need more or less carbon in our food in the same proportion: in Sweden more than in Sicily; and, in temperate climates, about an eighth more in winter than in summer. "Even when we consume equal *weights* of food in cold and warm countries, the articles of food are most unequal in the proportion of carbon they contain: the fruits on which the natives of the south prefer to feed, do not, in the fresh state, contain more than 12 per cent of carbon; while the bacon and train oil used by the inhabitants of the arctic regions, contain from 66 to 80 per cent of carbon."*

50. All chemical changes are attended with movement of the elements combining: a moving force is thus generated, by which vital activity is kept up; but every such movement is attended with a consumption of the parts

* Liebig, Anim. Chem. p. 17.

employed in giving rise to it. The combination of acid and metal in a galvanic battery which gives rise to extremely rapid movement and intense heat, consumes the metal; and every exertion of muscular force, being the result of chemical change, and consequent consumption of the parts, is attended by a proportionate exhaustion and necessity for renewal. Thus strong exercise increases the need for food in two ways; for it occasions more frequent breathing, and therefore a greater influx of oxygen into the system, and at the same time a waste of the substance of the body, which will require to be renewed.

51. In all these cases such is the exact regulation of the organs, that if the natural appetite be gratified, and no more than gratified, the bulk of the body will remain the same, as well as the temperature of the blood; although the body, as a heated mass, follows the laws of other heated masses, and loses heat again in proportion as the surrounding matter is colder or hotter than itself. This equality of the temperature of the blood in all climates is the result of the difference already mentioned in the quantity of oxygen respired. Carbon is the fuel, oxygen makes the fire: now exactly in these

cases where owing to external warmth the body loses less heat, and consequently needs less fuel to keep it up, the amount of oxygen inhaled is lessened by the rarefaction of the air. Even in cold climates warm clothing or warm rooms, by preventing the rapid cooling of the body, and the latter by rarefying the air, also lessen the demand for food. Those who remove to warm climates usually find their appetite diminished. "This is a warning from nature to diminish the amount of food taken: and if it were attended to, and the common, but absurd practice of stimulating the appetite by ardent liquors and hot spices, abandoned, Europeans might enjoy as good health in the East or West Indies as at home."* Hybernating animals which take no food during considerable periods,† breathe very slowly,‡ and grow cold during their winter sleep:—the small amount of carbon

* Turner's Elements of Chemistry.

† The dormouse is a familiar instance of this.

‡ A bat in a state of torpidity consumed on an average 3.4 cubic inches of oxygen gas in sixty hours: in a state of activity it consumed that quantity in less than half an hour. During the period of torpidity the temperature of the animal was that of the atmosphere. A dormouse when lively, with an external atmospheric temperature of 47°, had a temperature of 92°. The day before, when

burned by the oxygen received in respiration has in this case been supplied from the tissues of the body; for the animal loses flesh during its torpid state; but in order to meet this exigency, the abundance of food in the autumn fattens these animals exceedingly, so that a sufficient supply of carbon is found without fatally consuming the vital organs.

52. In cases of starvation not only the fat disappears, but also, by degrees, all such of the solids as are capable of being dissolved: the muscles shrink, grow soft, and lose their contractility, and with it, their power; till towards the end, the brain itself begins to undergo the process of oxidation, and delirium, mania, and death close the scene; that is to say, all resistance to the oxidizing power of the atmospheric oxygen ceases, and the chemical process of decay begins, in which every part of the body, the bones excepted, enters into combination with oxygen. The time which is required to cause death by starvation depends on the amount of fat in the body; on the degree of labour or exertion of

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torpid, its temperature was 52° the external thermometer then standing at 49°.—*Dr. Marshall Hall on Hybernation, Phil. Trans.* for 1832.

any kind; on the temperature of the air; and finally on the presence or absence of water. Water is a requisite component part of the body, and a certain quantity of it being constantly evaporated from the skin and lungs in consequence of a temperature of 98° Far., it must be supplied again, or its dissipation would hasten death.*

53. It has already been noticed (§ 47) that the increase of mass in the animal body, the developement of its organs, and of course the supply of waste, are dependant on the blood; for through it alone, the substances can be conveyed which are needful for these purposes. It is evident, therefore, that no substances can be considered nutritious which are incapable of conversion into blood; or which, being rendered fluid, and thus capable of absorption, are yet of a different nature from the usual constituents of any part of a healthy living body. Thus we find that the metals which have no place in the organism in its normal (i. e. natural and usual) state, when absorbed into the system in any

* Liebig. Anim. Chem. p. 27. He mentions a case where, with a supply of water but no food, life was prolonged for sixty days.

considerable quantity, act as poisons and destroy life, and the effect of some of them as medicines, when given in small doses, though still very obscure, probably depends on the unnatural action excited by them, which in some cases may be of service, by expelling diseased or useless matter.*

54. Blood when taken from the body, and thus withdrawn from the vital movement which has kept it fluid, separates into two parts; a deep red clot, or coagulum, and a yellowish liquid called *serum*, resembling white of egg with which it is identical in composition.† Like that, when boiled, it hardens into a white elastic mass which is termed *albumen*. The gelatinous clot when stirred with a stick adheres to it in soft elastic fibres, and this, which is identical with the muscular fibre, is termed the *fibrine* of the blood. It has already been seen (§ 25)

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* Some metallic poisons are such from their property of arresting the progress of vital change, which after all, is but incipient decomposition compensated by the activity of the organs in supplying fresh matter and expelling what has been decomposed. *Arsenious acid*, or as it is commonly called, *white arsenic*, stops the process of decomposition in the parts subjected to its influence even after death. *Perchloride of mercury* (*corrosive sublimate*) has a like property of arresting the progress of decay.

† Liebig. Anim. Chem. p. 41.

that these substances exist in the vegetables which form the food of the graminivora: in the carnivora they are supplied from the re-dissolution of the bodies they devour. Fibrine and albumen are nearly identical in substance: the following is the analysis of 100 parts given by Mulder:

	Albumen.	Fibrine.
Carbon	54.84	54.56
Hydrogen	7.09	6.90
Nitrogen	15.83	15.72
Oxygen	21.23	22.13
Sulphur	0.68	0.33
Phosphorus	0.33	0.36

but Mulder has also proved that these substances are but compounds of another, and yet simpler compound, which he calls *proteine* (from πρωτευω *I take the first place*) as being the original matter from which not only fibrine and albumen, but caseine* also, are derived.

55. Proteine is composed of carbon, hydrogen, nitrogen, and oxygen only: fibrine, albumen, and caseine, all contain small, but essential quantities of mineral substances, such as sulphur, phosphorus, potash, soda, common salt, and phosphate of lime. It has been proved by

* Vide § 19.

recent researches that animal and vegetable albumen, animal and vegetable fibrine, animal and vegetable caseine, are respectively identical in every particular. We may therefore assume that they are all compounds of proteine, with small proportions of inorganic matter. In every instance where they have been analyzed, it has been found that the amount of the four first elements in the precipitated proteine is the same as in the fibrine, &c. from which it has been precipitated. It therefore appears that it is one of those original compounds which the animal organism is incapable of preparing for itself: for it passes unchanged from the food to the blood, and from the blood to the more solid tissues deposited from it. It has been prepared in the secret laboratory of the vegetable organism, and is so essential to the animal creation that no substance which does not contain it in some shape, will support life. If in the course of animal assimilation it should have passed into actual fresh combinations of its elements, and the compound atom of proteine has been decompounded into another containing more or less of any of these four elements, it ceases to be nutritive. Thus gelatine, which is obtained from the cartilaginous parts of the body, and which, on analysis, shows these elements to be combined in different proportions, is incapable of supporting life. An animal fed upon it dies with the symptoms of starvation.

56. When food passes into the stomach it is subjected to the action of the gastric juice: a clear liquid always found there, but when no food is present, in a neutral state. When digestion has commenced, free muriatic acid * is found in it, arising probably from the decomposition of the common salt which is found in greater or less quantity in all that is taken as food, and which is generally sought by graminivorous animals, and by man when he is chiefly graminivorous, probably to furnish this necessary agent in the business of digestion. In the animal texture there is always a portion of it, and accordingly the carnivora do not seek it. But the solvent power of the gastric juice does not depend on the acid, for it is not found till the process of digestion has begun. Prof. Liebig is of opinion that this process is the result of the principle already noticed § 39, 40. He conceives that the surface of the stomach is subjected to a partial decomposition in consequence of the oxygen continually carried

* Or according to more modern nomenclature *hydrochloric acid.*

thither by the saliva; and that this action is communicated to the food as soon as it is received into it:—a fresh arrangement of atoms is in many cases the result—and in this case salt is separated into its acid and its base. All mineral acids have the power of arresting fermentation, hence the accumulation of the free hydrochloric acid finally puts a stop to further change. The food thus brought into a fluid state, and absorbed in the course of its passage through the stomach and intestines by the small vessels whose mouths open into these viscera, is carried finally into the larger vessels by the action of the heart, which does the office both of a sucking and a forcing pump, and after having drawn the venous blood towards it, and forced it into the lungs, where it is aërated, receives it again, and sends it as arterial blood to the extremities of the body.

57. We have already seen that the action of the oxygen carried by the arterial blood, produces a waste of the surfaces with which it comes in contact, by partial decomposition. The proteine having given up its carbon, either wholly or in part, to form carbonic acid, and its hydrogen and oxygen in like manner to form water, an excess of nitrogen remains mixed in the

blood. As this is now useless, the arterial blood undergoes a filtration in the kidneys, in the course of which, this, with a certain portion of the other elements, are passed off into the urinary bladder, and thus removed from the body. On returning towards the heart, the blood undergoes another filtration through the liver; and here the soda set free by the liberation of the hydrochloric acid in the stomach, and the remaining carbon not any longer entering into the composition of proteine, is separated, with a portion of hydrogen and oxygen, in the form of bile. It was formerly supposed that this was an excrementitious matter, and passed off through the intestines; but later researches have proved that it does not exist in the fæces, consequently it must be again taken up into the circulation, where it is supposed to supply the carbon needed for the process of respiration, and the generation of heat.*

58. Whilst contemplating the action of this nicely balanced machine, the question naturally arises, as to whence the provision is made for the growth of young animals; since so large a

* It is impossible to give the details by which these assertions are proved in the compass of this small treatise. In Prof. Liebig's works they will be found at length.

portion of the carbon received is consumed in the production of heat. There is a further provision for this. Milk is the nourishment of the young both of the graminivora and the carnivora, and in this there are, besides the compound of proteine termed caseine, two other products; butter and sugar of milk; neither of which contain any nitrogen, but which are rich in carbon: thus whilst the caseine is applied to the increase of the muscular parts, bones, &c.* the carbon and water of the other two supply the waste of respiration. It is observable that the carnivora, in their wild state, continue to suck till they have attained nearly their full growth: and, when domesticated, we find it needful to supply them with milk, if separated from the mother. In the young of carnivorous birds the total absence of movement so lessens the waste in respiration, that it compensates the want of this peculiar kind of nutriment. Man and the graminivora continue to make non-nitrogenized compounds a part of their food after milk has ceased

* "When chemically examined caseine is found to contain a much larger proportion of the earth of bones than blood does, and that in a very soluble form capable of reaching every part of the body."—*Liebig. An. Chem.* p. 52.

to be their only nutriment, and thus subsequent growth is provided for. Nothing but a very mistaken view of the animal mechanism therefore could induce any to feed children almost exclusively on a meat diet, and to debar them from the fruit and farinaceous food which their appetite always seeks: for it is in these latter that they find the sugar and starch which supply carbon for the respiratory process, and allow the compounds of proteine to be applied entirely to the support and growth of the body.

59. The same substances which during the growth of the young animal supplied the elements of respiration, and thus allowed an increase of mass, continue to form a considerable part of the food of herbivorous animals, and of civilized man even after this has ceased. If then the amount of oxygen breathed be not enough to consume the carbon of the food, a substance accumulates, which, in the normal state, only occurs in small quantity as a constituent of the nerves and brain. This substance is *fat*. If we compare the composition of sugar, of milk, of starch, and of the other varieties of sugar, with that of mutton and beef suet, and of human fat, we find that in all of them the proportion of carbon to hydrogen is the same, and that they only differ

in that of oxygen, which is deficient. The formation of fat, therefore, like other analogous phenomena in which oxygen is separated in the form of carbonic acid or water, will be attended with the disengagement of heat. This change supplies to the animal body a certain proportion of the oxygen indispensable for the vital processes, in those cases where the oxygen absorbed by the skin and lungs is not sufficient to convert the whole of the carbon fitted for such combination, into carbonic acid.*

60. In the case of carnivorous animals, or of men confined to an animal diet, the carbon of the flesh and blood must take the place of starch and sugar in keeping up respiration and heat; but 15 lbs. of flesh do not contain more carbon than 4 lbs. of starch: the consumption of the former, therefore, must be much greater when taken alone, than when a portion of vegetable matter is added; and in order to accelerate the waste of the organized tissues, so as to supply the carbon for respiration, long and severe muscular exertion is required. Carnivorous animals kept in a menagerie, and fed without the accustomed exercise of chasing and seizing their prey,

* Liebig. Anim. Chem. p. 93.

are in continual restless motion; and man upon a like diet, feels the same restlessness, and needs the like exercise for the very same reason. Those therefore whose profession, or whose amusements are sedentary, would find their comfort increased and health preserved, by avoiding a kind of diet which requires a larger amount of muscular exertion than they ever make, in order to carry on the vital processes; and which when this is not made, causes a degree of bodily uneasiness which cramps the best efforts of the mind, and much lessens the enjoyment of life.

61. Gelatine is the name which has been given to the jelly-like matter which cartilage resolves itself into wholly; and which is the nitrogenized portion likewise, of bones, hair, horn, feathers, &c. It is not like fibrine, albumen, and caseine, found in any vegetable matter—and yet it must be formed from the blood.—Prof. Liebig suggests that as "for the same amount of carbon, the membrane and tissues which yield gelatine contain more nitrogen, oxygen, and hydrogen than proteine does, it is conceivable that they are formed from albumen by the addition of oxygen, of the elements of water, and of those of ammonia, accompanied by a

separation of sulphur and phosphorus:" the sulphur is found in skin, hair, and horn, the phosphorus in the matter of the brain and nerves. But the question seems still involved in some obscurity.

62. Brain and nervous matter is distinct from all other animal tissues, and in its composition is intermediate between fat and the compounds of proteine; it contains nitrogen (which is absent in fats), but in far smaller quantity than is required to form proteine; and is, on the other hand, much richer in carbon than proteine or its compounds. It appears likewise to contain phosphorus as an essential ingredient.* From the circumstance that gelatine has less carbon and more nitrogen than the compounds of proteine, while nervous matter has more carbon and less nitrogen; it appears possible that the formation of the two bears some relation the one to the other. The tissue of the brain, especially the grey part, appears to be chiefly albuminous: but the white portions are loaded with the fatty matter above mentioned, which has the character of an acid. It is remarkable that the vegetable alkalaids which may be reckoned among

* Turner's El. of Chem.

the most active remedies in medicine, bear no relation to any constituent of the body excepting the substance of the nerves and brain." All of them contain a certain quantity of nitrogen: and in regard to their composition, they are intermediate between the compounds of proteine and the fats. But in one point the substance of the brain differs from them in its chemical composition, for it exhibits the characters of an acid, and contains far more oxygen than the organic bases or alkalaids. We observe that quinine and cinchonine,*—morphia and codeine †—strychnine and brucia ‡—which are respectively nearly alike in composition, if they do not absolutely produce the same effect, yet resemble each other in their action more than those which differ more widely in their composition. We find that their energy of action diminishes as the amount of oxygen they contain increases, (as in the case of narcotine) and that, strictly speaking, no one of them can be entirely replaced by another. If these compounds then are capable of taking a share in the formation, or in the alteration of the qualities of brain and

* The active principles of Peruvian bark.

† Ditto of opium.

‡ Ditto of nux vomica and some other plants.

nervous matter, their action on the healthy, as well as the diseased organism, admits of a surprisingly simple explanation.*

63. Bones are formed of gelatinous tissue and bone earth. The earthy matter forms rather more than half the weight of the bone, and contains a variable proportion of carbonate of lime, but the chief ingredient is a peculiar phosphate of lime. Fluoride of calcium is sometimes, but not always, found in recent bones, in fossil ones always. Teeth contain the same ingredients as bones, but the proportion of earthy matter is greater; nearly 70 per cent. The enamel of the teeth contains no animal matter, and fluoride of calcium is found in it. In rickets the proportion of earthy matter in the bones is much diminished.†

64. Thus far the animal body has been considered in its usual and healthy state; but it is subject to derangements of that state, from external as well as internal causes. The great law of organic matter,‡ by which substances, in a state of chemical change, communicate their movement to other substances at rest, gives rise

* Liebig. Anim. Chem. p. 186.

† Turner's El. of Chem.

‡ Vide § 33, 34.

to many morbid affections. If putrid flesh, that is, flesh in a state of chemical decomposition, be applied to a wound, so as to find access to the blood, even in very small quantity, it communicates its movement to the particles with which it first enters into contact; this to the next, and so on, till the decomposition is complete; and death ensues, unless the progress of chemical change can be arrested, or unless it be slower in its operation than the formation of fresh blood. From this, as a well known fact, we may argue as to many more less understood. The virus of small pox, &c. which reproduces the disease when communicated to the blood of a healthy individual, probably acts in the same way, for though the exact chemical change which takes place has not been ascertained, we may judge from analogy that such is the case. When yeast is introduced into beer to occasion fermentation, it occasions a change in the saccharine matter it finds there, and its elements assume a new form very rapidly, but it acts differently on the gluten. This enters into a state of much slower decomposition, resembling that of the like substance introduced in the shape of ferment or yeast. The same thing probably happens in the human body. The compound atom, introduced whilst undergoing chemical change, communicates movement to all,—but its own peculiar kind of change only to those of a like composition. Thus a nitrogenized compound, in a state of decomposition, sets all the compound atoms round it in motion, and, if the chemical affinity of their constituent parts be weak, causes them to make fresh combinations among themselves by the mere disturbance, as is the case where sugar is fermented by means of putrid blood, or flesh, or yeast indifferently. A change takes place, but no part of the substance introduced finds a place in the new combination. But if this compound nitrogenized atom should find other atoms of a like composition, then it communicates to them its own peculiar state of change as long as it is itself undergoing the process, and the virus, like yeast, is reproduced until the fresh combinations are completed. This may possibly explain the apparently unaccountable circumstance that many diseases can be taken but once. If the chemical action terminate in forming compounds of a different nature from those in which the action began, then until matter of a like nature is reproduced in the course of time by the organism, the disease cannot be reproduced. It may be that some compounds, when once decompounded, are formed no more: in this case there can be no return of the malady.

65. In the above mentioned cases the organism probably suffers from a morbid decomposition of its parts, in consequence of the introduction of some substance in a like state of decomposition; and if the vital force, whatever it be, should be unequal to combating this inorganic movement, a total dissolution of the organism must be the result. Instances of this kind go far to prove that the vital force, like other forces by which matter is impelled, has its laws and its limits. Growth, the first effort of the living organism has its period: the resistance of other forces here curbs the vital force.—A malignant virus overpowers it by a more intense chemical action; and death, the entire termination of its power, seems little else than the gradual encroachment of other forces on this, till the organism, step by step, loses the power of assimilation; the processes of respiration are impeded: and the fire goes out for want of fuel. Our stoves present the type of our own frail life.

CONCLUSION.

THERE is a peculiar characteristic of TRUTH, whatever be its subject, that has seldom been noticed as it deserves to be;—namely, its tendency to throw light on objects apparently the most remote. So distinctive a character indeed is this, that it would be almost a conclusive argument against the truth of a theory, if it could be shown that it had no bearing on any science beyond the one to which it immediately applies; and if this be a test of truth, few theories have a larger claim to being received as such than that of Professor Liebig. Without assuming that it has yet, on all points, that experimental proof, which alone can give a stable foundation to any hypothesis, however probable it may be rendered by argument; whoever studies his works cannot hesitate in agreeing with Dr. Gregory,* that if we "are only at the

* See his edition of Turner's Elements of Chemistry.

commencement of a period which promises to be richer in valuable discoveries, and in applications to the benefit of mankind than any which had preceded it;" it is "he who has led the way in those important investigations, the effect of which, on the progress of discovery, will long be felt."

It is not alone on Agriculture, on Medicine, or on Chemistry, in general, even, that this new radiance has fallen:—there is scarcely a subject connected with man's existence on this globe, which does not receive some elucidation from it; and many a long established error fades before its light. Among these may be reckoned the opinion, which at one time, it would have been almost heresy to question, that the soul and the life were identical. Whatever be the nature of that power, which the learned professor has well characterized, as a disturbing force, found only in man: it is clear that it is perfectly distinct from that life which the human being, in common with the whole animal creation, shares with the vegetable. And here the chemist steps in to correct the ascetic and the enthusiast, by showing him that the tendencies of vegetative life neither can nor ought to be rooted out; though it is in the power of the disturbing, or as we might better term it, the intellectual force, to modify their manifestation sufficiently for all the purposes of virtue and of happiness. Again, what more satisfactory answer can be given to the materialist, who would find the whole of man in organized matter, than the proved existence of this disturbing force in the human animal alone: a force by whose influence the phenomena of animal and vegetative life are frequently so palpably altered, as to compel the acknowledgment that it is perfectly distinct from the vital force which manifests itself in those phenomena. The chemist has traced this latter to its elements: he has accounted for the processes of life, and the causes of death; but he has seen in the course of his investigations that another agency exists, and confesses that its nature is inscrutable to him. The vital force has its limits;—to the intellectual we have not yet been able to set any. It overcomes the vital force, and produces death;—we can trace its action no further; but as the agent and the patient must be different, it is at least a rational inference that the agent does not itself share the fate of the machine, which it has worn out by too much use, or broken in a fit of ill humour.

Doubts have been entertained by some wellmeaning persons as to the use of scientific enquiry: it has been thought needless; and some have gone so far as to think it even hurtful;—filling us with a vain conceit of human learning, and dangerous to faith, which ought, they say, to be taken from God's revealed will only. Yet if ever a doubt should arise in the mind as to whether what purports to be God's revealed will, be really so—how are we to answer it?—It can only be by the most scrutinizing scientific investigations that we can arrive at the certainty that the Creator and the Lawgiver are the same—that certainty once attained what doubt can then annoy us?—and that certainty is attainable: for every step in true knowledge brings us nearer to the FOUNTAIN OF ALL TRUTH. The chemist shows that the most probable order of creation would be none other than that delivered down to us by the great Jewish legislator:—the chemist has proved man's dual life:—the chemist has given us some of the best lessons of the wisdom and the benevolence of the Creator: for if the vastness of space, which the astronomer has opened to us, be so crushing to human intellect, as to make man,—the worm—bow in the very dust before Him who measures the heavens in the hollow of his hand,—no less does the almost infinite minuteness of the atoms out of whose regulated movements so fair a world has grown, impress the mind with the Omnipotence of that Being whose influence stretches to objects which *we* cannot even perceive by any of our senses; and only become cognizant of by reason—that image of God within us.

It would be a curious, but too long, and as yet too theoretical a research for the present brief sketch, to trace the gradually simplifying principles of science till they might haply be discerned to merge in one*—to find in the universe a first and a second cause only. Every discovery of modern science has tended more and more to this point: and however wild our grandfathers might have thought such a proposition, no philosopher now will wholly reject it.—It has been seen in the course of the preceding pages that life is but chemical change: and chemical change is but the movement of elemental atoms determined by a law of their nature impressed on them from the beginning. Sound is but the vibration of the air beating on

* V. Davy's Elements of Chemical Philosophy, pp. 223, 488.

the tympanum of the ear: light the undulation of a perhaps yet more subtle medium impressing the optic nerve: magnetism is a movement of electric origin:—electricity is intense and rapid chemical change—and heat, so closely connected with this latter in numerous phenomena, has by some, perhaps with justice, been considered as a vibration of the elemental atoms already mentioned. It may be long ere experimental proof confirms what as yet can only be considered as a not irrational hypothesis; but should such proof finally be given, we may find at last that Moses, when he wrote, "God said Let there be light, &c." did not merely enunciate a sublime idea, but recorded a great fact; little, if at all, understood for nearly four thousand years, but beginning now to loom upon us in the distance, in all its immensity. We have proof from the phenomena attending the polarization of light, that it is, as Huygens long ago asserted, an undulatory movement. Liquids which remain fluid in the dark, crystallize when exposed to the light;—for it gives the movement requisite to the re-arrangement of their particles:—and if our system, as is not unjustifiably conjectured by some, were originally but a quantity of nebulous matter, gradually solidified, we may as easily conceive the expanded mass crystallizing into shape under the new influence of the undulations of light, as the liquid in the vial which we have taken from the cellar, and placed in the window, doing the like. But how overwhelming to our finite intellect is the power and the knowledge which, by one simple agent, and one simple law, could regulate alike the production of a world, or of a grain of salt! Would the devout man ever again part with such an anchor of faith as this, when once his understanding has found its use?—The events of this world may look dark, but has not He, who from its very foundation, so regulated all things by His first fiat, that not an atom of that mass, in all its countless changes, is ever lost, or ever useless—so regulated also the moral order of His creation, that "all things," as the sacred text expresses it, "work together for good to those that love Him."

It is in the enlarged views which science gives, that we first learn duly to appreciate the Deity. Eternity, infinity, omnipotence, are attributes so astounding to human faculties, that we can only arrive at the most moderate apprehension of them by steps;—Jacob's ladder must stand upon the earth in order to reach to heaven.—

What more worthy employment, then, can man find for the faculties God has so richly bestowed upon him, than the investigation of those hidden forces which tell, in so plain a language, of the Mighty Power which called them into action? Before such knowledge superstition necessarily fades, like darkness before the sun, and more worthy notions of the Deity, and of man's business upon earth, must necessarily be formed. We may safely aver that no chemist and astronomer of the present age could be an idolater. Let us not then underrate the value of science: let us not suppose that it is merely good for the navigating of the ocean, or for giving impulse to a steam engine, or permanence to a dye: all this it may do, but it does much more—while it improves our bodily comforts, it also elevates the mind to a state of more spiritualized feeling; —teaches us to despise the low pleasures of earth; and to strain forwards towards that higher meed which is alone worthy the aspirations of a human soul; and whilst shedding blessings around us in this present world gently leads us on to a better.

CHARLES WHITTINGHAM, CHISWICK.

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